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Compressive strength, drying shrinkage and chemical resistance of concrete incorporating coal bottom ash as partial or total replacement of sand

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HIGHLIGHTS

- Paper presents the potential of coal bottom ash (CBA) in production of concrete.
- Sand is replaced with 20%, 30%, 40%, 50%, 75% and 100% CBA.
- Compressive strength and durability properties of concrete are presented.
- Relation between chloride permeability and compressive strength is presented.

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ABSTRACT

Coal bottom ash produced in large volumes by the coal fired thermal power plants is being dumped on land adjoining their sites over the years. Stockpiling of coal bottom ash on land is causing air pollution as well as posing a danger to living beings. The present research was aimed to evaluate the potential of coal bottom ash as fine aggregate in concrete. Utilization of coal bottom ash in the manufacturing of concrete will present economical as well as ecological way of their disposal and conserving the natural resources. The results of mechanical properties of concrete incorporating coal bottom ash were encouraging. Evaluation of durability aspects of concrete incorporating coal bottom ash as a sand replacement is as important as the mechanical properties. In this study compressive strength and durability aspects of concrete such as drying shrinkage, chloride ion penetrability, resistance to external attack of sulphate and sulphuric acid were examined by performing laboratory test. The test results indicate that bottom ash concrete exhibit better dimensional stability, slightly better resistance to sulphuric acid attack as compared to conventional concrete. Performance of bottom ash concrete under sulphate attack was almost identical to that by control concrete. No weight loss and reduction in compressive strength of bottom ash concrete specimens were observed after 180 days of immersion in 10% magnesium sulphate solution. No sign of sulphate attack was observed during examination of SEM image and XRD spectrum of concrete samples immersed in sulphate solution up to 180 days. Bottom ash concrete showed better resistance to chloride ion penetration.

1. Introduction

The investigations carried out by the researchers in the past have made it possible to manufacture durable concrete using industrial waste products. The industrial waste materials, which have been successfully used in manufacturing durable concrete, are blast furnace slag, fly ash, silica fume, red mud aggregate, etc. In some research reports coal bottom ash, the by-product of coal fired thermal power plants has also been targeted as replacement of natural sand in concrete. Coal bottom ash is produced in large volumes throughout the world. In India, about 30 million tons of coal bottom ash is produced annually on combustion of 407 million tons of coal. Huge quantities of coal bottom ash are being disposed off on open land adjoining thermal power plants sites over several years. Ministry of environment, government of India has issued guidelines for 100-percent utilization of coal ash by the power generation utilities. Till date, no emphasis has been given for utilization of coal bottom ash by the power utilities. Coal bottom ash is simply disposed off on open land, which poses environmental danger to the living beings. It is now a global concern to find environment friendly solutions for the safe disposal

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of industrial wastes to sustain a cleaner and greener environment. In the developed countries, coal bottom ash has been investigated for various uses. Utilization of coal bottom ash is the only attractive proposition to its disposal. Due to ever-increasing quantities of coal bottom ash and scarcity of land, utilization of coal bottom ash is becoming a necessity rather than a choice. Several researchers have targeted coal bottom ash as partial replacement of natural sand in concrete. The published data indicates that coal bottom ash is a suitable material to be used as fine aggregate in the manufacturing of concrete [1,2]. Concrete incorporating coal bottom ash as fine aggregate showed encouraging results in respect of strength properties and micro-structural properties [3]. However, till date a limited research literature on durability properties of concrete containing coal bottom ash as fine aggregate has been published. The meticulous investigations of concrete containing coal bottom ash as fine aggregate in respect of its durability properties are required before the coal bottom ash is widely accepted as construction material in production of concrete. The stability and durability of concrete made using industrial waste material over the intended life of the structure is the utmost importance. Concrete made using waste materials can be regarded as durable concrete if it retains its original form, quality and serviceability when exposed to weathering action, abrasion, chemical attack and other processes of deterioration for the intended period. Water, fire, acids, salt solutions or organic chemicals can attack concrete. In case of acid attacks, the damage can be catastrophic. Moisture movements in concrete result in deterioration of concrete due to sulphate attack and corrosion of reinforcement steel. Permeability is the main character, which influence the durability of concrete. Permeability of concrete further depends on the micro and macro-cracks and voids developed in it. The cracks in concrete can develop due to restraints to volume change. The reports published by various researchers indicate that bottom ash concrete has lower chloride permeability as compared to natural sand concrete. The permeation of chloride ions into the bottom ash concrete decreased drastically when a low dosage of super plasticizer was used [4,5]. Concrete made with coal bottom ash as a sand replacement has a higher water absorption as compared to conventional concrete [6]. The dimensional stability of concrete also plays an important role in performance of concrete. Concrete incorporating coal bottom ash as fine aggregate exhibit better dimensionally stability. Drying shrinkage strains of bottom ash concrete are lower than that of control concrete [7,8]. Roller compacted concrete made with coal bottom ash as fine aggregate exhibit excellent resistance to external sulphate attacks and performs well in an environment with repeated freezing and thawing cycles [9]. Conventional concrete made with coal bottom ash as sand replacement also displays a remarkable performance when exposed to an environment with repeated freezing and thawing cycles. The addition of super plasticizers has minimal effect on freezing and thawing resistance of the bottom ash concrete [4,5].

The aim of this research work was to study the performance of concrete made with coal bottom ash as river sand replacement under external chemical attack. The properties of concrete investigated in this study include compressive strength, drying shrinkage, rapid chloride ion penetration and resistance to external attack of sulphate and acid. The above properties of bottom ash concrete mixtures were compared with those of conventional concrete.

2. Experiment details

2.1. Characterization of materials

2.1.1. Cement

The ordinary Portland cement used in this study fulfilled the requirements of BIS: 8112-1989 [13]. The chemical composition, fineness, setting times, consistency and compressive strength of cement used in this study are given in Table 1.

2.1.2. Coal bottom ash

Coal bottom ash was collected from Guru Hargobind Thermal Power Plant Bathinda, India. The chemical properties and physical properties of coal bottom ash are presented in Tables 2 and 3 respectively. The chemical analysis of coal bottom ash was performed using EDS. Fig. 1 shows the SEM image and EDS spectra of coal bottom ash. The chemical analysis shows that coal bottom ash is mainly composed of silica, alumina and iron with small amounts of calcium, magnesium sulphate etc. The sum of the percentage of SiO_2, Al_2O_3 and Fe_2O_3 present in the coal bottom ash is 94.12. The loss of ignition of coal bottom ash was less than 1%. The physical properties of coal bottom ash were determined as per BIS: 2386 Part III-63 [15]. The specific gravity of coal bottom ash measured by pycnometer method was 1.39. Fineness modulus and water absorption of coal bottom were 1.37 and 31.58% respectively. X-ray diffractogram of coal bottom ash is shown in Fig. 2. The X-ray diffractogram shows that quartz, tridymite, anorthite and mullite are the main phases present in coal bottom ash. The SEM image shows that coal bottom ash has spherical and irregular shaped, complicated textured and porous particles.

2.1.3. River sand

Sand was collected from quarry on Ghaghar River near Chandigarh, India. The sand used in this study was conforming to grading zone III of BIS: 383-1960 [12]. The results of specific gravity, water absorption and fineness modulus of Ghaghar river sand are presented in Table 3.

2.1.4. Coarse aggregate

Crushed stone aggregate used in this study was collected from Pathankot quarry. Specific gravity, water absorption and fineness modulus of coarse aggregate were 2.68, 0.39% and 6.27 respectively. The maximum size of coarse aggregate was 20 mm.

2.2. Mix proportion

The conventional concrete mix was designed as per the procedure given in BIS: 10262-1982 [14]. Oven dry river sand and coal bottom ash was used in this study and fixed quantity of water was added in all the concrete mixtures. The river sand was replaced with coal bottom ash by mass in concrete. The mixture proportions of bottom ash concrete and control concrete are given in Table 4.

2.3. Casting and curing of specimens

The ingredients of concrete were mixed in 0.06 m^3 capacity mixer. Weighed quantities of cement, sand and coal bottom ash were dry mixed until a uniform colour was obtained without any cluster of cement, sand and coal bottom ash. Then weighed quantity of coarse aggregate was added and mixed in a dry state until homogenous mix was obtained. Measured quantity of water was added in two equal parts. All the moulds were oiled before casting the specimens. Cube of size 150 mm × 150 mm × 150 mm of each concrete mixture were cast for determining the compressive strength. Cylindrical specimens of size 100 mm × 200 mm were cast for determining the chloride ion penetration. Cube specimens of size 100 mm × 100 mm × 100 mm were cast for determining the resistance of concrete to external acid attack. Prism specimens of size 75 mm × 285 mm were cast for measuring the length change when the specimens were exposed to air-drying and were immersed in 10% magnesium sulphate solution. The specimens were de-moulded after 24 ± 1 h of adding water to the concrete mixture. After demoulding the specimens were cured in water at room temperature.

2.4. Test procedures

2.4.1. Compressive strength

Compressive strength of concrete specimens was determined at 7 days, 28 days, 90 days, 180 days and 365 days curing age as per BIS: 516-59 [16]. Saturated surface dry cubes were placed in 3000 kN compression testing machine and load

Table 1
Chemical and physical properties of cement.

Chemical composition		Physical properties	
Lime saturation factor	0.877	Fineness (Sq m/kg)	278.6
Ratio of alumina and iron oxide	1.51	Initial setting time	125 min
Loss on ignition (%)	1.93	Final setting time	175 min
Total sulphur content SO_3 (%)	2.10	Compressive strength	
Magnesia (%)	0.97	3 days	32.0 MPa
Insoluble residue (%)	1.85	7 days	40.3 MPa
Alkalies K_2O (%)	0.4	28 days	51.5 MPa
Total chloride content (%)	0.020	Consistency (%)	28
Na_2O (%)	0.10	Specific gravity	3.13